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SYSTEMS OF CROPPING IN THE DRY TROPICAL ZONE OF WEST AFRICA - WITH SPECIAL REFERENCE TO SENEGAL[+]

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In this paper we shall review the following items: Systems of cropping, rotations, multiple cropping, experimental data concerning the combinations of mineral fertilization and soil tillage, and economic considerations. We shall also discuss the problems of soil management in the main ecological regions in the dry tropical zone of West Africa and suggest measures for the future agricultural development of this zone.

1. SYSTEMS OF CROPPING

It is convenient to distinguish four broad categories of systems of cropping, differing in their degree of intensity: (a) Present peasant systems or so-called 'traditional' system, (b) improved traditional systems, (c) semi-intensive systems, and (d) intensive systems of cropping. Their main characteristics will be described, referring mainly to Senegalese examples before discussing their comparative effects on soils, crops and economic returns.

1.1 Present Peasant Systems of Cropping

The present peasant farming systems or so-called 'traditional' systems have undergone numerous and great changes. These changes have resulted from increasing population pressure and from the development of

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cash crops; they concern mainly the duration of the fallow period and the ratio of cultivated to fallow land.

The main characteristics of these systems may be summarized as follows:

Progressive clearing of land; removal of stumps, if any.

'Half' shifting cultivation: The villages are permanent, only the fields change. The cropping cycles are broken by fallows, the duration of which is decreasing more and more.

Livestock may be present, but there is no true mixed farming. Owing to the lack of animal power, it is not possible to have deep tillage and to incorporate harvested residues or grass fallow into the soil.

Owing to inadequate equipment, there is poor control of weeds.

Mineral fertilization is absent or inadequate.

The number of plants which can be cropped is limited, species and varieties having high requirements for water; and mineral elements cannot be utilized.

Rotations are more or less without definite plan.

Association of plants on the same field (multiple cropping) is frequent.

Selected varieties are little used.

Control of diseases and parasites is inadequate.

As noted above, despite low yields, such systems can no longer maintain soil fertility, in contrast to former traditional systems based on short cropping cycles and long resting periods.

1.2 Improved Traditional Systems

As a first step, agronomists tried to improve the peasant systems of cropping without upsetting the basic system and using only techniques adapted to the very low financial resources of farmers. Efforts were made successively on the following:

Use of high-yielding and disease-resistant varieties.

Disinfection of seeds, which is an inexpensive and beneficial operation; in some cases (mainly for cotton), control of diseases and pests during the vegetative cycle.

Improvement of cultural techniques: plant population, planting in rows making hand or mechanical control of weeds easier, adequate timing of cultural operations, use of horse draft and light equipment for planting, application of fertilizers, and mechanical weeding.

Use of low amounts of mineral fertilizers in the most profitable crops to minimize the burden on the farmers' finances.

Adoption of defined cultural successions and intercultivation in the rotations of short-lasting grass fallows.

1.3 Semi-intensive Systems

Compared with the preceding systems, semi-intensive systems are characterized by the development of mechanized cultivation by drought-oxen. This implies total removal of stumps and permanent settlement of fields. Regular plowing brings about an improvement of soil macro-structure, promotes better plant rooting and helps in the control of weeds, thus resulting in increased yields. In these systems the land under grass fallow or green manure is plowed every four or five years. Only superficial tillage is practised in the other years. Crop rotations are interrupted every four or five years by a grass fallow which does not last more than one or two years. Grass fallow is often replaced by a green manure crop, generally pearl-millet or sorghum, planted at high density as a forage crop and the regrowth plowed under after grazing. As in the preceding systems, improved cultural techniques, varieties, and weed and disease-control practices are followed. Mineral fertilization is heavier and additions of mineral elements are calculated to maintain soil fertility.

1.4 Intensive Systems

In these systems, there is continuous cultivation without interruption of the rotation by resting periods of fallow or green manure. Plowing land under fallow or green manure is replaced by plowing under straw of short season cereals. Plowing and incorporation of vegetative matter in the soils are made as often as possible. Due to the objective of plowing under straw, the use of new, short season varieties of cereals is more common than in the preceding systems. In some cases animal power is replaced by motor power.

Table 1 summarizes the main technical characteristics of the systems of cropping described above.

2. ROTATIONS

Rotations vary according to the various systems of cropping.

Table 1. Major Characteristics of the Various Systems of Cropping Investigated in Senegal

Systems of cropping	Type of cultivation	Type of management Systems	Removal of Stumps	Soil tillage	Rotation	Fallow	Crop residues	Weeding	Mineral Fertilization
1. Present systems (F_0T_0)	Hand	Shifting cultivation	Very incomplete	Superficial	No fixed plans	Variable duration burned	Removed from field or burned	Hand — inadequate	Nil
2. Improved traditional systems (F_1T_1)	Horse or mule draught	Partially shifting cultivation	Partial	Superficial	4-6 years rotation including fallow	1-3 years duration burned	Burned	Hand and mechanical	Slight
3. Semi-intensive systems (F_2T_2)	Oxen draught	Permanent cropping	Total	Plowing under fallow	4-5 years rotation including fallow	1-2 years of grass fallow or green manure plowed under	Burned	Mechanical and hand; adequate	Heavy
4. Intensive systems	Oxen draught or tractor	Permanent cropping	Total	Plowing under crop residues	Continuous cropping	No fallow	Mostly plowed under	Mechanical, hand, and chemical; adequate	Heavy

2.1 Rotations in the Present Peasant Systems and in Improved Traditional Systems

In the present peasant systems, it does not seem that precise rules exist for crop sequences. The latter depend mainly on the food crop to cash crop ratio, which is largely influenced by the population and ecological conditions. The number of combinations is indeed limited, as few species and varieties can be cropped under conditions of low fertility.

In the improved traditional systems, the number of cultivated plants is also limited due to inadequate improvement of soil properties. In Senegal, for example, only two cereals, pearl-millet and sorghum, and two legumes, groundnut and cowpea, are commonly cropped in these systems. Other crops, such as cassava, may be grown outside the rotation. The most commonly recommended rotation is: Grass fallow - groundnut - cereal - groundnut. The duration of grass fallow is theoretically a function of the ecology. It is one or two years in the wet southern zone and three to four years in the dry northern zone. In fact, the duration of fallow is largely determined by the population pressure. In some regions where the population is more than 70 to 80 inhabitants per square kilometer, fallows have practically disappeared. In these systems where plowing is not practised, fallows are burned before cultivation.

Attempts have been made to analyze the agronomic effects of these short-period grass fallows (Charreau, 1972-73).

Compared to the annual cropping, the beneficial effects of fallows on soil properties can be listed as follows:

Better protection of soil against wind and water erosion, mainly during the dry season and at the beginning of the wet season;

A slight action of roots on soil structure; this action is less localized than that of annual crops (mainly cereals) and concerns the whole surface of the field;

A noticeable influence on the phosphorus-potassium balance, due to the decreased removal by vegetation;

A specific effect on the potassium nutrition of the crop due to the increase in potassium availability.

As for the humus balance, the effect of these short-period grass fallows does not seem to differ significantly from those of annual crops.

The disadvantages of grass fallows in relation to annual crops are the following: Increase in weeds making weed control more difficult for the following crops; waste of water stored in soil at the beginning of the dry season, which may result in very depressive effects on the succeeding crop if rains at the beginning of the following wet season are inadequate; and economic deficit, which can be partly offset if the grass fallow is used as a temporary meadow for cattle grazing.

Effects of length, nature and various treatments of grass fallows on crop yields were studied in many long-term experiments, especially by IRHO[1] in Senegal (IRHO-Senegal, 1960-1968; IRHO-Senegal, 1962-68). From these data, it seems that the effects of burned short-term grass fallows on crops yields would be of some importance in the poorest and driest regions (northern and central Senegal) and of little importance in the regions where soils and climates are more favorable to agriculture, as in southern Senegal (Charreau, 1972-73).

2.2 Rotations in the Semi-intensive Systems of Cropping

In the semi-intensive systems of cropping, the duration of grass fallow is reduced to one year. It can, however, be two years, in the driest regions. As the grass fallow is incorporated in the soil by plowing at the end of the rains, effects on soil properties are much more beneficial than in the case of burned grass fallow. Soil macro-structure is largely improved for two or three years, resulting in beneficial effects on rooting of the succeeding crop. Water stored in the soil profile by the end of the rainy season is conserved throughout the dry season. Control of weeds is easier. Effects on the humus balance are likely to be more marked, although there is little evidence of this. Grass fallow can be replaced by a green manure or an annual forage crop. Pearl-millet and sorghum, planted at high density, are most commonly used for this purpose. By the end of August, the forage is mowed and the regrowth is plowed under by the end of September or in October. It is thus possible to combine the benefits of soil improvement and of forage production. Such green manures or annual forage crops have about the same benefits on soils as grass fallow but they usually have a higher production in dry matter and are more easily mowed and plowed under than natural grass fallow. On the other hand, their extension to farmers is more difficult (Charreau and Nicou, 1971).

After plowing under the fallow or green manure, the cropping sequence which has been recommended for a long time in Senegal is the same as in the improved traditional systems of cultivation, that is: one year of fallow or green manure plowed under - groundnut - cereal - groundnut or cowpea. The cereal usually is a long-season pearl-millet or sorghum.

2.3 Rotations in the intensive systems of cropping

In these systems, recently studied, the resting period is eliminated and plowing under grass fallow or green manure is replaced by plowing

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[1] Institute de Recherches pour les Huiles et Oleagineux or Research Institute for Oil and Oil Crops.

under straw of short-season cereals. The beneficial effects on soil properties have proven to be about the same (Charreau and Nicou, 1971). This was made possible by the recent development of new short-stem and short-cycle varieties of cereals: pearl-millet, sorghum, maize, and rain-fed rice.

As soil fertility is largely improved by soil tillage, incorporation of organic matter and sufficient addition of mineral fertilizers, more species and varieties of plants can be cropped. Thus cropping sequences are also more varied.

Some general rules can be drawn from rotation trials conducted in Senegal (IRAT-Senegal, 1972):

(i) Groundnuts grow well after any crop but benefit little from plowing and incorporating vegetative matter into the soil. Groundnut is a good crop to precede any cereal, especially rain-fed rice.

(ii) Cotton gives the best yields after maize, groundnut, and pearl-millet. It is better to avoid growing it after sorghum. Two successive years of cotton within three years of cultivation is not recommended. Cotton is the best crop to precede maize.

(iii) Crops suited for growing before maize are: Cotton, green manure or grass fallow plowed under, groundnut. Maize is the best crop to precede cotton.

(iv) Rain-fed rice is not a good crop to precede any crop. On upland soils, two successive rain-fed rice crops must be avoided. Groundnut is the best crop to precede rain-fed rice.

(v) Sorghum grows well after any crop, especially after cotton and groundnut. On sandy to coarse loamy soils, sorghum is a poor crop to precede many crops and in particular cotton and sorghum itself. It is better to avoid growing two successive sorghum crops and even two sorghum crops within three years.

On these bases, several models of rotations were proposed for the different ecologic zones of Senegal. The major characteristics of these zones are summarized in Table 2.

In the northern and central zones, the rainfall is low and irregular and the introduction of new crops is difficult without irrigation. The major crops grown are groundnut (several varieties), pearl-millet, and to a lesser extent, sorghum and cowpea.

Due to the short and variable rainy season, plowing after early groundnut and early pearl-millet are possible in some years but not every year. It is, therefore, necessary to use pearl-millet as a green manure

Table 2. Major Characteristics of the Main Ecological Zones in Senegal

Zone	Mean annual rainfall mm	Number of humid months (R > 50 mm)	Main parent materials	Main Soils
Northern	250 - 500	2-3	Eolian deposits[1]	Brown and reddish brown sub-arid (Orthids)[1]
Central	500 - 750	3-4	Eolian deposits	Slightly leached ferruginous soils (Orthids and Ustropepts)
Sine-Saloum	750 - 900	4-5	(Eolian deposits) + Clayey sandstones from continental terminal[2]	Leached ferruginous soils (Haplustalfs, Paleustalfs, Phinthustalfs) + slightly desaturated impoverished ferrallitic soils (Alfic Eutrustox)[2]
Eastern	750 - 1000	4-5	Clayey sandstones from continental terminal[3]	" " "
Southern	1000 - 1500	5-6	"	" " "

1 Also in this zone are alluvial deposits of the Senegal River with hydromorphic and halomorphic soils occupy a large area.

2 Also in this zone are alluvial soils of the Sine, Saloum and Gambia Rivers, with hydromorphic and halomorphic soils occupy a large area.

3 Also in this Zone, toward the southeast, are primary outcrops with various rocks and soils.

or have a grass fallow plowed under at the beginning of the rotation. The classic four year rotation: Fallow or pearl-millet as green manure - groundnut - cereal - groundnut is always of value.

As a cereal does better than groundnut after the fallow or green manure is plowed under and as the effects of this plowing last more than three years a five-year rotation may also be recommended: Fallow or green manure - pearl-millet - groundnut - pearl-millet - groundnut. Other rotations making broader use of groundnut as a cash crop may also be considered and are under study.

In the Sine-Saloum and the eastern regions, three crops recently introduced are in progressive development. They are: cotton, maize and rain-fed rice. In these regions the rainy season is long enough to enable one to replace the plowing under of fallow or green manure with the incorporating of the straw of short-season cereals into the soil. This technique has the same benefits for the soil as plowing under the green manure or grass fallow with an additional benefit resulting from easier control of weeds for the following crops.

On these bases many combinations are possible for a four-year rotation.

For the first year, there is a choice between a fallow or a green manure plowed under or a short-season cereal (maize, rain-fed rice, early pearl-millet), the straw of which incorporated into the soil by plowing,

For the second year: Cotton or groundnut,

For the third year: Long-season cereal (sorghum, late pearl-millet, rain-fed rice),

For the fourth year: Groundnut.

The balance between food crops and cash crops is adequate. From this model many combinations are possible providing substantial flexibility in the choice of rotation. The most common rotations in these regions are: (a) Fallow plowed under groundnut - sorghum - groundnut, (b) Fallow plowed under cotton - sorghum - groundnut, and (c) Early pearl-millet or maize - cotton - sorghum or rain-fed rice-groundnut.

In the southern region it is impossible to grow cotton due to the high rainfall resulting in a high incidence of diseases. Groundnut is, therefore, the only cash crop. On the other hand, the ecological conditions are favorable for all cereals, which can produce high yields. From an agronomic standpoint, it would be feasible to establish rotations where cereals predominate, but from an economic standpoint there is a marketing problem in the sale of cereals for livestock production, a problem which is not yet solved in Senegal.

Two kinds of rotations are presently practised:

(1) A four-year rotation: Fallow plowed under-maize-rainfed rice-groundnut; or

(2) A three-year rotation: Maize (with straw incorporated into soil)-rain-fed rice or late pearl-millet - groundnut.

Studies on rotations are still going on in Senegal and other countries of dry West Africa. Special attention should now be paid to two topics which might become of increasing interest due to present changes in economic conditions. They are: (i) The use of legumes as an annual forage crop and/or green manure for replacing grass fallow, or cereals used as forage or green manure, and (ii) the introduction in the rotation of annual or perennial crops with deep rooting, such as Cajanus cajan (Pigeon-pea).

Legumes as green manure or/and forage were studied many years ago in French-speaking countries but for various reasons, both technical and economic, they were judged to be of secondary interest and their study was somewhat neglected. As nitrogen fertilizers are now very expensive in these regions, and as substantial progress has been achieved in recent years in soil and crop science, including inoculation of legumes, this question should be examined again with a new perspective.

In the same manner, deep-rooted plants would be useful for recovering the mineral elements lost by leaching from surface soil layers. This would save appreciable amounts of fertilizers. Lucerne (alfalfa) plays this role in temperate and Mediterranean countries. Pigeon-pea (Cajanus cajan) or other plants could play a similar role in tropical countries. More thorough studies should be undertaken on this.

3. MULTIPLE CROPPING

Multiple cropping is the general rule in traditional systems of cropping. The most common associations of plants in the same field are: Groundnut and cereals (pearl-millet or sorghum) and pearl-millet and cowpea (in the northern zone). Multiple cropping has many advantages in the exploitation of moisture and mineral reserves of the soil by the differential rooting of the crops, more effective use of light, the modification of microclimate, and the soil cover. Some experiments on multiple cropping have been carried out in Senegal (Nicou, 1964-65; Charreau and Nicou, 1971; Schilling, 1965) and in Niger (Nabos, 1963-65); they generally showed a slight agronomic superiority of multiple cropping over monoculture.

In mechanized systems, however, single cropping is generally preferred to multiple cropping because soil tillage, planting, mechanical weeding, and fertilization are done more easily in this system.

Some recent experiments in an equatorial or humid tropical zone with or without irrigation (Bradfield, 1970) have showed that mechanization and multiple cropping are not incompatible. The use of the soil is very intensive and the productivity per surface unit reaches record levels. The cultural system is very sophisticated and cannot be practised by farmers unless an effective extension service is developed. For this reason, such systems cannot be extended very widely but can be used as reference models.

In the dry tropical zone, possibilities of land use without irrigation are less and experiments on intensive multiple cropping are few. Some carried out in northern Nigeria, however, gave promising results. More such studies need to be carried out.

4. EXPERIMENTS ON SYSTEMS OF CROPPING IN SENEGAL

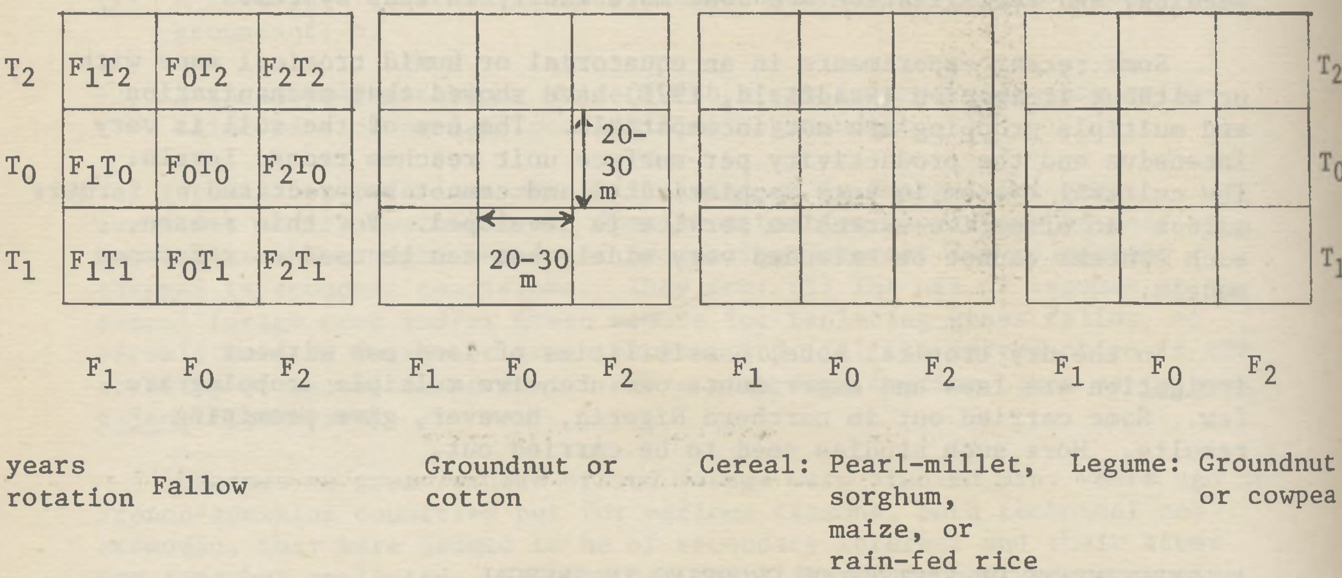
4.1 Generalizations

Separate and combined effects of soil tillage, the incorporation of vegetative matter in the soil, and mineral fertilization have been studied in long-term factorial experiments in Senegal since 1963. These experiments were carried out at about 15 sites, distributed in the various ecological regions of the country (IRAT-Senegal, 1972).

At all sites crops were in a four-year rotation but the rotation varied from one site to another. All crops of each rotation were represented every year. There was no replication. So at each site the experiment comprised four blocks - each block having one crop of the rotation for the year considered. The area of the blocks ranged from 4000 to 9000 m^2. As shown in Table 3 each block contained nine plots. The area of these plots ranged from 400 to 900 m^2, which was much larger than the area of the usual experimental plots (30 to 50 m^2) and approached the area of farmers' fields. The nine plots represented the nine treatments in the factorial combination of two factors, each of them at three levels. The factors were: Mineral fertilization and soil tillage. The levels of mineral fertilization were: F_o, and F_1, and F_2. The amounts of mineral fertilizers corresponding to these different levels are shown in Table 3. Level F_1 corresponds to the fertilization levels which are presently recommended. Level F_2 corresponds to fertilization recommended in semi-intensive systems.

Levels of soil tillage are: T_o, T_1, and T_2. Corresponding treatments

Table 3. Factorial Experimental Designs for the Study of the Combined Effects of Soil Tillage and Mineral Fertilizers in Senegal



Soil tillage: T

T_0: Superficial hand tillage - burning of fallow and harvested residues

T_1: Superficial tillage with horse draft - burning of fallow and harvested residues

T_2: Plowing under of the fallow with oxen draft - burning of harvested residues

Mineral Fertilization: F

F_0: No mineral fertilization

F_1: Light annual complete fertilization
- Groundnut and cowpea: 150 kg/ha of 6-20-10
- Cereals: 150 kg/ha of 14-7-7
- Cotton : 50 kg/ha of ammonium sulphate + 50 kg/ha of dicalcic phosphate

F_2: Heavy fertilization, distributed over the rotation
- Fallow : 500-700 kg/ha of rock phosphate (190-266 kg of P_2O_5/ha)
- Legumes: 91 kg/ha of KCl (55 kg of K_2O/ha) + 30-50kg/ha of ammonium sulphate
- Cotton : 133 kg/ha of ammonium sulphate + 62 kg/ha of KCl + 17 kg/ha of dicalcic phosphate
- Cereals: 150 kg/ha of ammonium sulphate + 60 kg/ha of urea.

are indicated in Table 3. T_1 corresponds to superficial tillage with horse draft which is recommended for the improvement of traditional systems; T_2 corresponds to soil tillage used in the semi-intensive systems, that is, only one plowing during the four-year rotation. This plowing incorporates the vegetative matter of grass fallow into the soil.

Among the nine factorial combinations studied, only three will be considered here. They are: F_o T_o, F_1 T_1, and F_2 T_2; these combinations correspond to three systems of cropping.

F_oT_o is the so-called 'traditional' system, that is, the present system without mineral fertilization, without adequate soil tillage, and without incorporation of vegetative matter into the soil. Only hand cultivation is practiced. In these experiments, the F_oT_o treatment actually is an improvement of the traditional system because crops are in a regular rotation, varieties are improved, plant population is increased, and timing of cultural operations, weeding, and control of diseases are adequate.

F_1T_1 corresponds to the 'improved traditional systems', that is the system which is presently recommended for extensive use.

F_2T_2 corresponds to the 'semi-intensive' systems which are used by advanced farmers in limited areas. The four-year rotations are shaped as follows:

First year - Grass fallow everywhere

Second year - groundnut, cotton or maize

Third year - cereal (pearl-millet, sorghum, maize, rain-fed rice)

Fourth year - groundnut or cowpea

4.2 Agronomic Results

Comparative agronomic results for various crops and regions are shown in Table 4.

As can be seen from these data for all plants and all regions, crop yields were higher in the improved traditional systems (F_1T_1) than in the peasants' systems (F_oT_o), and they were higher in the semi-intensive systems (F_2T_2) than in the improved traditional systems (F_1T_1)[1]. Differences between F_1T_1 and F_oT_o were generally higher than that between F_2T_2 and F_1T_1. Substantial increases in yields, however, could

[1] An exception is groundnut in the central zone.

Table 4. Comparative Agronomic Results from Three Systems of Cropping in Senegal, for Various Crops and Regions*

Crops	Regions	Number of experimental sites	Years of comparison	Number of annual results	Yields kg/ha			Yield indices		
					F_0T_0	F_1T_1	F_2T_2	F_0T_0	F_1T_1	F_2T_2
Pearl-millet	Northern	2	66-70	9	578	689	948	84	100	133
	Center	3	65-70	13	366	688	999	53	100	145
	Southern	3	63-70	13	1,105	1,763	2,429	63	100	138
	Weighted mean	8	63-70	35	695	1,088	1,517	64	100	139
Sorghum	Sine-Saloum	5	65-70	28	893	1,597	2,100	56	100	131
	Eastern	4	65-68	9	1,086	1,723	2,729	63	100	158
	Southern	1	67-68	2	1,617	1,905	2,190	85	100	115
	Weighted mean	10	65-68	39	975	1,642	2,166	59	100	132
Maize	Eastern	1	66-68	3	792	1,338	2,425	50	100	182
	Southern	1	67-70	4	168	1,284	2,684	13	100	209
	Weighted mean	2	66-70	7	436	1,308	2,573	33	100	197
Rain-fed rice	Southern	3	68-71	9	443	1,711	2,630	26	100	154
Cotton	Eastern	2	65-68	6	1,109	1,531	2,061	67	100	135
Ground-nut	Northern	2	65-70	10	861	920	1,044	94	100	114
	Center	3	65-70	30	998	1,238	1,154	81	100	93
	Sine-Saloum	5	65-70	52	1,454	1,732	1,997	84	100	115
	Eastern	4	65-68	26	1,426	2,232	2,339	64	100	105
	Southern	3	63-70	19	1,644	1,905	2,072	86	100	109
	Weighted mean	17	63-70	137	1,311	1,669	1,821	79	100	109
Cowpea	Northern	2	65-70	9	653	727	875	90	100	120

* Source: IRAT - Senegal, 1972

Mineral fertilization
- F_0: No fertilization
- F_1: Light fertilization
- F_2: Heavy fertilization

Soil tillage
- T_0: Hand superficial tillage
- T_1: Superficial tillage with horse draft
- T_2: Deep tillage (plowing) with oxen draft

Systems of Cropping
- F_0T_0: Traditional shifting cultivation
- F_1T_1: Improved shifting cultivation
- F_2T_2: Semi-intensive cultivation

be obtained going from F_1T_1 to F_2T_2. The magnitude of these increases depended on (a) the ecological zone and (b) the nature of the crop. In general, increases were higher in the southern and eastern zone than in the northern and central zone. They were also generally higher with cereals and cotton than with groundnut.

4.3 Economic Data

Economic calculations were made in these experiments to compare the net benefits from the various systems of cropping. These benefits have been calculated per unit area and per man.

Income per unit area. As the rotation was the same for the three systems, the net benefits per unit area could be computed from the equation:

$$E = \underset{\sim}{M} \times S - Cf \qquad (1)$$

where E = net benefits for the area in the rotation

$\underset{\sim}{M}$ = difference between gross returns and variable costs of the rotation

S = area of the rotation in ha

Cf = fixed charges for the area of the rotation.

As $\underset{\sim}{M}$ and Cf are constant for a given site, E is a linear function of S.

Calculations were made in 1972 in Francs C.F.A., which is the currency used in Senegal (IRAT-Senegal, 1972). They were then transformed into U.S. \$ on the basis of 1 U.S. \$ = 250 Francs C.F.A.

It should be mentioned that due to recent increases in the cost of fertilizers after the energy crisis, the same calculations made in 1974 would result in quite different figures. Net benefits would be lower in F_1T_1 and F_2T_2 systems.

Calculations of $\underset{\sim}{M}$ included on one hand the value of the crops and on the other, the cost of seeds, pesticides, and fertilizers used in the various systems. The cost of fertilizers was by far the most important of the inputs.

Calculations of Cf included the annual charges of amortizing the purchase of draft animals and mechnical equipment and the annual expenses for feeding draft animals.

The area which can be cropped by one draught animal and the corresponding mechanical equipment are limited and variable in the different zones. It depends mainly on weed control which requires an increasing number of work hours going from north to south. Areas which can be cropped by one drought animal in the different regions are as follows:

	Northern and central regions	Sine-Saloum region	Eastern region
F_1T_1 (1 horse)	8 ha	6 ha	4 ha
F_2T_2 (1 pair of oxen)	16 ha	10 ha	8 ha

Above these area limits the farmer must buy a second draught animal with the corresponding mechanical equipment. This results in a doubling of the annual fixed charges and a break in the linear curves representing the net income versus the cropped area.

Comparisons of net incomes versus cropped areas in three systems of cropping are shown in Figs.1 and 2 for four regions in Senegal. They concern five rotations with various crops.

As can be seen, the net incomes are very variable depending on the regions. They are low in the northern and central regions where climates and soils are not favorable to agriculture; they increase in the Sine-Saloum and, above all, in the eastern region where both climates and soils are better.

Economic responses to the three systems of cropping are also quite variable depending on the regions and the rotations. Considering Fig.1, it is seen that improved systems are not profitable in the northern zone; in the central zone with higher rainfall, the economic result of improved systems approach those of traditional systems on sandy soils; in the same zone, but on more clayey soils (Interdune) where sorghum can be cropped instead of pearl-millet, profits are higher on F_2T_2 than on F_0T_0 and F_1T_1, resulting from large increases in yields of sorghum through plowing and heavy fertilization.

In Fig.2, the three systems of cropping show little differences in profits in the Sine-Saloum region in contrast to the eastern zone where profits from F_1T_1 are clearly higher than from F_0T_0 and profits from F_2T_2 are clearly higher than from F_1T_1. It will be noted that differences in profits between F_2T_2 and F_1T_1 increase in this zone when cotton is substituted for groundnut as the second crop of the rotation.

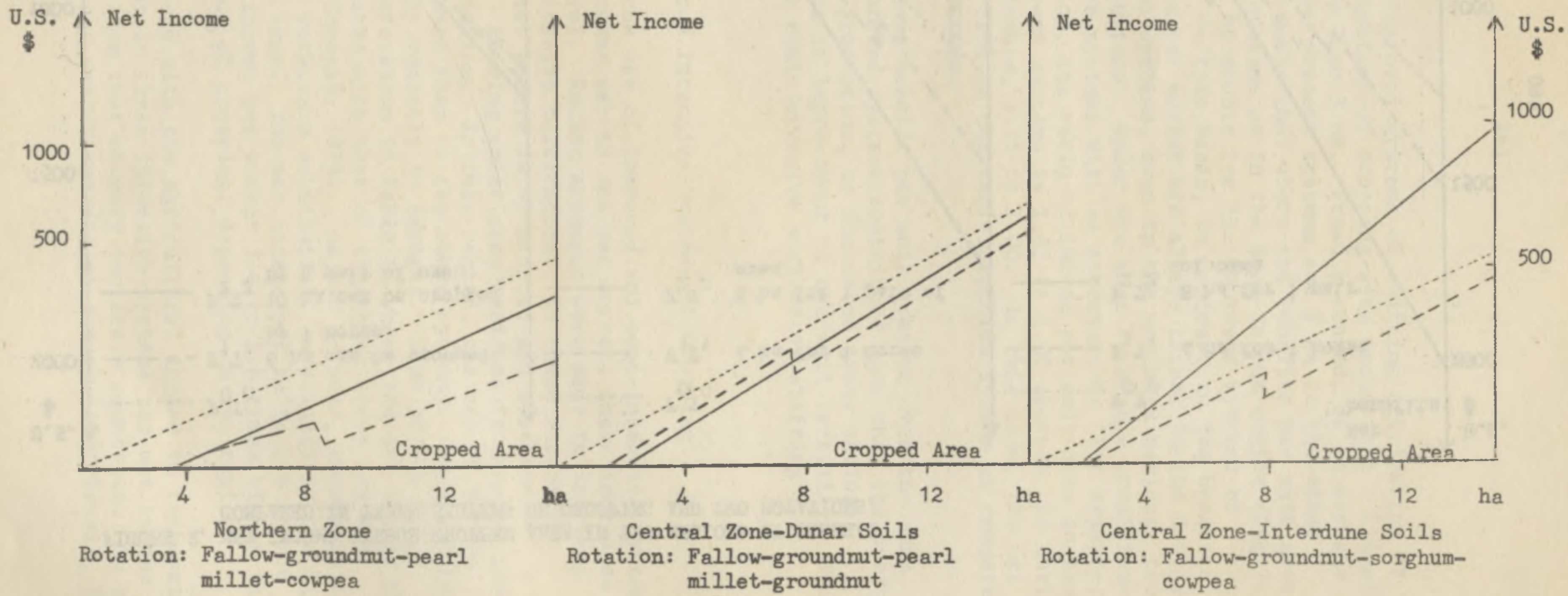
<u>Income per worker</u>. In the present systems of cropping (F_0T_0) with hand cultivation, one man can crop 0.8 to 1.2 ha depending on the region

FIGURE 1. NET INCOME VERSUS CROPPED AREA IN TWO REGIONS OF SENEGAL COMPARED IN THREE SYSTEMS OF CROPPING AND THREE ROTATIONS.

- - - - - - - - F_0T_0 Traditional shifting cultivation

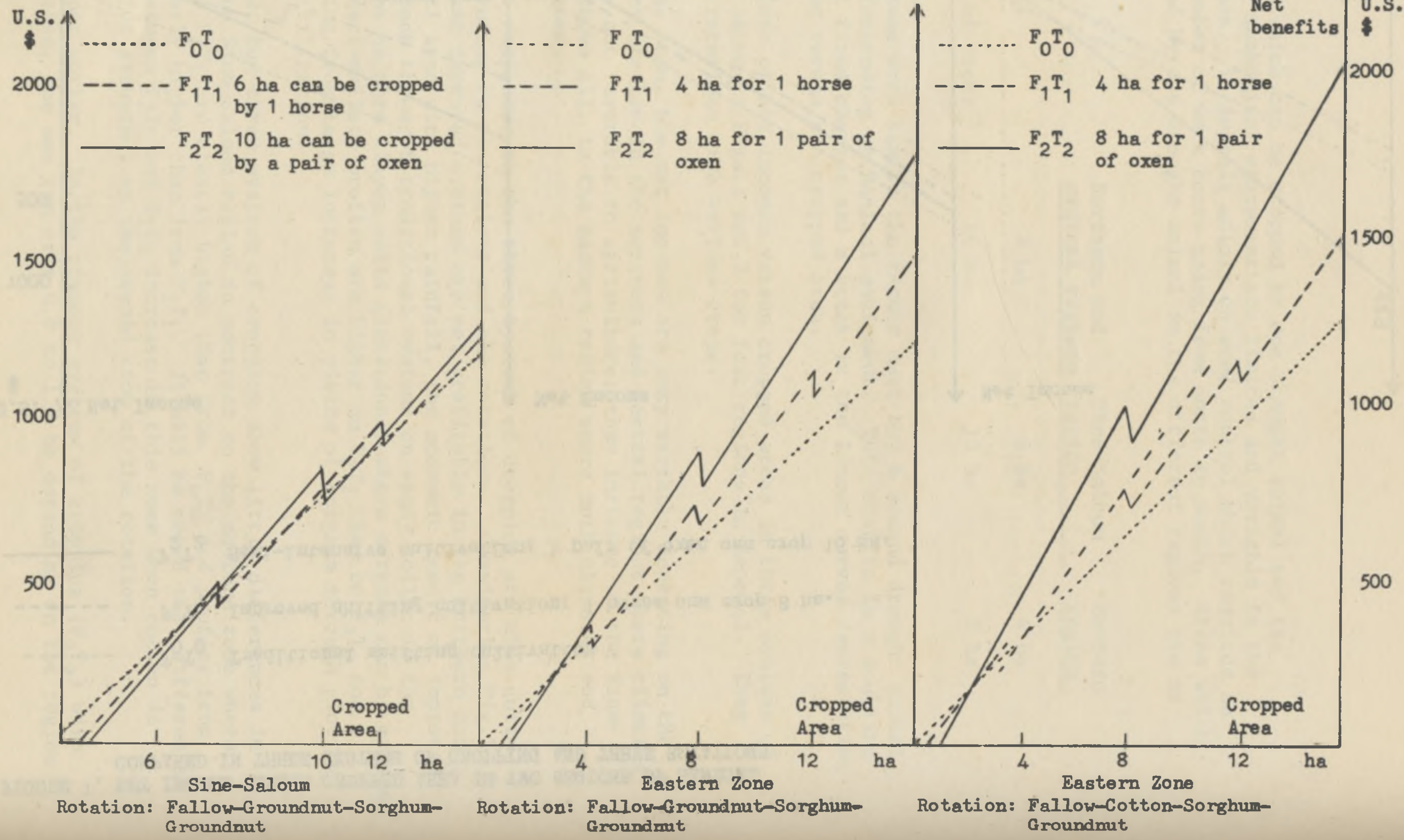
\- - - - - - F_1T_1 Improved shifting cultivation; 1 horse can crop 8 ha.

———— F_2T_2 Semi-intensive cultivation; 1 pair of oxen can crop 16 ha.



Source: IRAT -. Senegal, 1972.

FIGURE 2. NET INCOME VERSUS CROPPED AREA IN TWO REGIONS OF SENEGAL COMPARED IN THREE SYSTEMS OF CROPPING AND TWO ROTATIONS.



and the rotation. In the improved systems of shifting cultivation (F_1T_1) and in the semi-intensive systems of cropping with mechanized cultivation (F_2T_2), one worker can crop 2 to 3 ha. Broadly stated, on an average one man can crop 1 ha in the present systems and 2 ha in the other systems of cropping. This means that where the benefits per unit area are the same in the three systems as in the Sine-Saloum region (Fig.2a) the income per worker will be double for the improved systems of cropping (F_1T_1 and F_2T_2). On this basis, in contrast to the benefits per unit area, the benefits per worker are always higher in the improved systems than in the present systems, even in the northern regions, the most unfavorable for agriculture. Under the most favorable conditions, the differences between the systems will be accentuated. For example, in the eastern zone (Fig.2c), the ratio of income per unit area in the semi-intensive to the present systems is 1.62 to 1.00 whereas the ratio of incomes per worker is double, 3.24 to 1.00. In this case, the net income per worker reaches \$250 in the semi-intensive system as compared with \$78 in the present systems.

Moreover, given the same benefit per unit area or even the same benefit per caput, the improved systems contribute more than the present systems to increased food production, to increased gross national product, and to maintenance or improvement of the soil fertility. This is especially true for the semi-intensive systems of shifting cultivation (F_2T_2).

4.4 Preliminary Results from Intensive Systems of Cropping

Despite progress in the use of improved and semi-intensive systems for increasing the net incomes per ha and per worker, these increases remain at a rather low level. Recent attempts were made to increase the net income by more intensive cultivation. In these intensive systems the fallows or green manure is eliminated and continuous cultivation is practised. Plowing under crop residues is done as often as possible during the rotation. In this regard, the use of short-season cereals is more common than in the other systems. Experiments on these systems began only recently in Senegal. Some of the first results of these systems are shown in Table 5, where the net income per ha and per worker is compared with that of the three first systems previously studied (IRAT-Senegal, 1972). As can be seen, increases in net income per ha and per workerare substantial, especially in the Sine-Saloum and in the central zone. The net income per ha is 1.3 to 2.6 times higher and the net income per worker 3.6 to 5.6 times higher than that of the present systems of cropping, depending on the region.

If a comparison is made with the agricultural income in temperate countries, it appears that in these intensive systems the net income per ha is not very different from that of many temperate countries. On the contrary, the net income per worker remains at a much lower level. The

Table 5. Mean Net Income per ha per Worker in Various Systems of Cropping in Different Regions of Senegal

Systems of Cropping	Years of study	Number of sites studied per region	Net incomes per ha, U.S. $				Net income per worker[1], in U.S.$			
			Northern zone	Central zone	Sine-Saloum	Eastern zone	Northern zone	Central zone	Sine-Saloum	Eastern zone
1. Present Systems (F_0T_0)	1965–70	2–5	36	46	75	77	36	46	75	77
2. Improved Systems (F_1T_1)	1965–70	2–5	19	40	74	93	38	80	148	186
3. Semi-intensive systems (F_2T_2)	1965–70	2–5	30	43	91	114	60	86	182	228
4. Intensive Systems	1970–71[2]	1	—	119	131	133	—	258	310	279

1 The net income per worker was estimated for the three first systems and was measured for the fourth system

2 Except for the eastern zone where only the year 1971 was considered

Source: IRAT-Senegal, 1972

differences in human productivity can be largely explained by the special difficulties of weed control in the dry tropical area. This problem might be resolved by a wider use of chemical herbicides and of tractors.

5. CONCLUSIONS

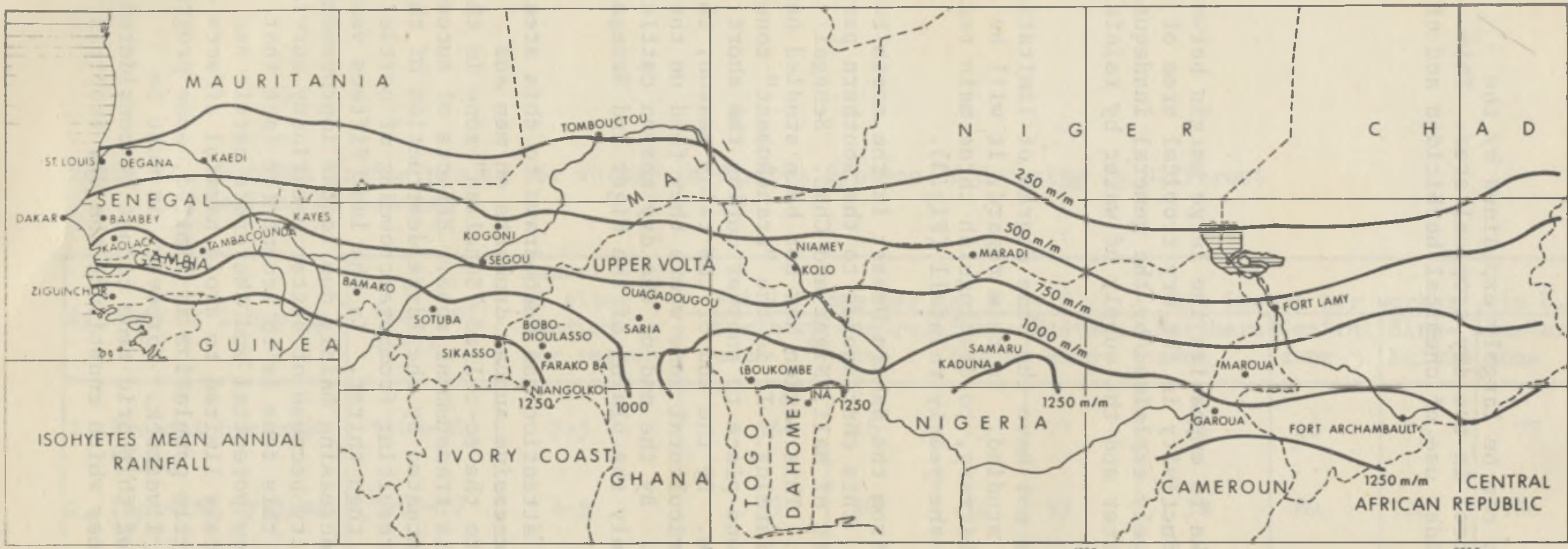
In conclusion, I would like to emphasize the large margin between the potential and the actual productivity in the dry tropical area of West Africa. This margin is largely explained by the general inadequacy between the needs of crops for water and the supply of water by rainfall throughout the year.

This factor, however, does not have the same degree of limitation for crops everywhere in the area studied. In this regard, it will be convenient, although somewhat arbitrary, to distinguish three main regions in the area studied according to the yearly rainfall (Fig.3).

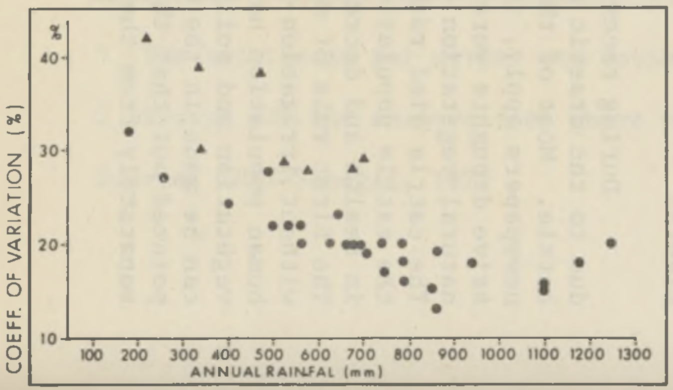
The first region extends from the Sahara Desert in the north to the 250 mm isohyet to the south. This corresponds to the southern part of Mauritania and the middle parts of Mali, Niger and Chad. Senegal and Upper Volta are not included. This region has not been studied here, because there is practically no farming. It is the "transhumant" zone where herds of cattle move from one place to another during the short rainy season in search of pasture. By the end of the rainy season, the herds move southward into the agricultural zone where they feed on the crop residues in farmers' fields. By the end of the dry season cattle gather in the wettest areas, mainly the plains of the Niger and Senegal Rivers.

During recent years world attention has been drawn to this area due to the drastic effects of successive annual droughts on men and cattle. Most of the references to the so-called "Sahelian" zone in the newspapers apply, in fact, to this transhumant zone. Effects of successive droughts were greatly accentuated by the large destruction of the natural vegetation in this area resulting from overcrowding of cattle. The cattle died rather of hunger than thirst. In the last fifteen years, the cattle population has been increasing mainly due to the improvement in health and decrease in mortality because of better veterinary services. The first rule of management for this zone is to accept the fact that without irrigation it has very low potential and therefore cattle and human population have to be severely limited to avoid harmful effects on vegetation and soils. If the cattle population is limited, some progress can be made in the management of livestock. Moreover, it must be pointed out that the management of this arid zone cannot be considered separately from the other two zones which constitute the dry tropical

Fig. 3. MEAN ANNUAL RAINFALL IN THE SEMI-ARID AREA SOUTH OF THE SAHARA



MEAN ANNUAL RAINFALL VS. COEFFICIENT OF VARIABILITY



TRIANGLES REPRESENT PLACES IN WEST SENEGAL AND N'GUIGMI.

SOURCE: COCHEME, J., AND P. FRANQUIN. 1967. A STUDY OF THE AGROCLIMATOLOGY OF THE SEMI-ARID AREA SOUTH OF THE SAHARA IN WEST AFRICA. FAO/UNESCO/WMO INTERAGENCY PROJECT ON AGROCLIMATOLOGY. ROME.

area of West Africa. This is not only because countries like Mali, Niger, and Chad comprise within their boundaries both arid and semi-arid zones, but also because these two zones are largely complementary and because trade between herders and farmers has always existed from the beginning of settlement and will continue.

The second region extends from the 250 mm isohyet in the north to the 750 mm isohyet in the south. The duration of the rainy season ranges from 60 to 120 days; for a given annual amount of rainfall it is shorter on the Atlantic side (Senegal) than for the countries in the interior. This zone corresponds to all of the area cropped in Niger and between one-third and one-half of the area cropped in Senegal, Mali, Upper Volta, and Chad. It also includes a part of northern Nigeria and northern Cameroon. Without irrigation, potential productivity in this area is limited by the shortness of the rainy season and the variability of rainfall from one year to the next and its erratic monthly distribution. Also the soil is a limiting factor because about 15 percent of the soils are inadequate for agriculture owing to the shallow depth and iron pans. Due to the shortness of the rainy season, the number of species which can be cropped is limited. Rotations should include a resting period with grass fallow or green manure to plow under and incorporate vegetative matter into the soil atleast once in the rotation, however short the rainy season. Despite these adverse factors, improvements of varieties, cultural techniques, and mineral fertilization can give yields of cereals more than double of that from present systems as shown by examples in the preceding tables for Senegal. Increases in yields of legumes are, thus far, less and range from 20 percent to 80 percent. Moreover, good possibilities of irrigation exist in this zone in the plains of the Senegal and Niger Rivers and around Lake Chad. They involve more than 1,000,000 ha but require heavy investments for building dams and channels. Other sources of surface and ground water are more limited but should not be neglected.

The third region extends from isohyet 750 mm in the north to a southern limit which is better defined by the maximum duration of the rainy season (150 days), than by the mean annual rainfall. Depending on the region, this limit of maximum duration corresponds to a mean annual rainfall ranging from 1,000 to 1,300 mm. This region includes all of Gambia and most of the southern part of Senegal, Mali, Upper Volta, Chad, northern Nigeria and northern Cameroon. Important areas of soils with shallow depth to iron pans can also be found in this region, but the constraints of variable rainfall and duration in the rainy season are much less than in the foregoing region. The number of species which can be cropped is larger and continuous cropping is possible provided that good cultural techniques, application of sufficient mineral fertilization, and regular plowing under of crop residues are done. The present available technology is adequate to more than double the yields of the traditional cereals, pearl-millet and sorghum, and to multiply three to ten times the yiedls of cereals, that is maize and rain-fed rice, with high input requirements recently developed in this region. As for the cash crop, the yields of cotton can be more than doubled and the yields of groundnut can be increased from 10 to 80 percent. Examples of these increases are shown in Table 4 for Senegal.

Not only in the last two regions discussed above does the improvement in systems of cropping results in large increases of yields but it enablesone to maintain and even to increase the soil fertility, whereas the present systems of farming have led to a slow but steady degradation of the soil. This does not mean at all that the presently available technology is perfect and that no technical obstacles exist any longer. On the contrary, substantial progress can be expected from the development of new improved varieties, a better knowledge of the water-soil-plant relationships, a better understanding of the nature of organic matter in the soil, the practice of liming, the use of chemical herbicides, the management of soils with high potential productivity, such as the Vertisols, and many other factors.

But these technical obstacles seem to be of relatively little importance compared to the enormous economic obstacles resulting from the present general situation in these countries. The ratio of input to output, that is, manufactured products to price of crops, is very unfavorable in these countries even when products are manufactured locally because of the use of some imported products. So the use of manufactured products necessary for the improvement of agriculture, mainly fertilizers and mechanical equipment, is severely restricted everywhere. The general situation has recently worsened due to the energy crisis. Actually, in this context few countries in the region are able to make substantial progress in agricultural development with their own resources. Most of them urgently need increased help from industrialized countries. For the latter the question is whether it is better to give food periodically to these countries to prevent general starvation or to provide the means to enable them to make significant progress in food production. There is no doubt that the second alternative is much better than the first if only the interest of these African countries is considered.

In addition to economic obstacles, there are also human and sociological problems. In many cases special methodologies would have to be developed to extend new technology to the farmers more effectively. Sociological changes will result from the adoption of new technology. These changes will have to be foreseen and controlled to avoid social disorders.

To sum up, substantial increases in agricultural production are possible in these countries even in the less favorable regions but technical improvements will be of little or no effect if they are not accompanied by important efforts in the economic and human fields. It is hoped that this global effort will be expanded to correct the present serious situation in these countries and to reduce the increasing economic gap between them and the industrialized countries.

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